

# Balun Cores

Part Number	Fig #	Length A (mm)	Width B (mm)	Height C (mm)	ID D (mm)	E (mm)	wt/k ggs	Electrical Properties					
								25		28		35	
								L	Z @ 300 MHz 3 Turns	L	Z @ 150 MHz 1 Turn	L	Z @ 10 MHz 1 Turn
*N0136-00P	1	3.45	2.01	2.36	0.86	1.45	0.06	0.050	14.26	0.576	37.00	2.96	50.00
*N0136-10P	1	3.45	2.01	1.50	0.86	1.45	0.04	0.029	8.00	0.197	20.76	--	--
*N0136-30P	1	3.45	2.01	1.65	0.86	1.45	0.06	--	--	--	--	1.60	30.86
*N0138-00P	1	3.45	2.01	0.68	0.86	1.45	0.02	0.014	3.63	--	--	--	--
*N0252-000	2	6.35	--	6.35	1.19	3.05	0.88	0.383	90.07	--	--	9.90	105.00
*N0277-00P	1	7.04	4.06	6.20	1.80	2.90	0.61	0.229	57.00	1.920	114.00	--	--
*N0372-00P	3	9.40	5.35	8.00	2.59	5.24	1.46	--	--	--	--	7.00	154.00

Figure #1

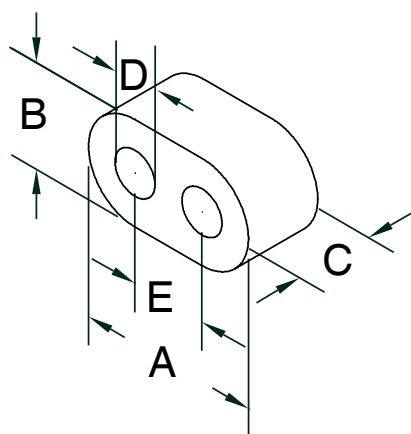


Figure #2

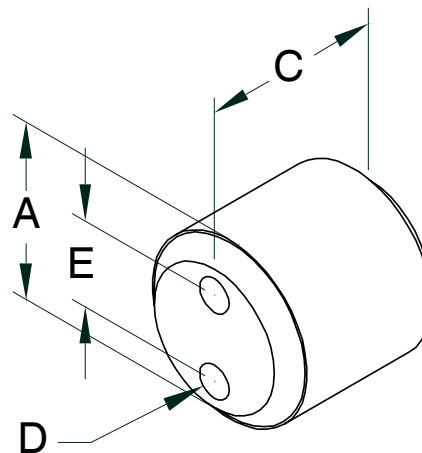
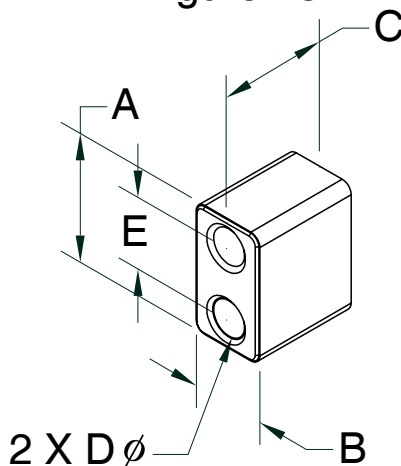


Figure #3



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# Ferrite Property Measurement

## Initial Permeability, Losses & Inductance Factor

Three properties can be measured, using an inductance meter to measure an equivalent series inductance and resistance. From these values, and a knowledge of the inductor sample, these parameters may be derived. These are:

Inductance Factor,  $A_L$ , given by

$$A_{L[nH/t^2]} = \frac{L_{[nH]}}{n^2}$$

where  $L$  is the inductance in nH, and  $n$  is the number of turns,

Initial Permeability (the real part only),  $\mu_i$ , given by

$$\mu_i = \frac{L}{L_o}$$

where  $L$  is the measured inductance, and  $L_o$  is the air core inductance.

Losses, described by  $\tan\delta/\mu_i$ , given by

$$\frac{\tan \delta}{\mu_i} = \frac{L_o R_s}{\omega L^2}$$

where  $\mu_i$  is the initial permeability,  $\tan\delta/\mu_i$  is the lossy component of the total reactance,  $\omega$  is  $2\pi f$ , and other terms as defined above.

*Equipment:* Precision LCR meter.

*Test Conditions:* Flux Density < 10 Gauss

*Frequency:* as specified.

The core is stabilized at room temperature (22° C) and wound with the correct number of turns. Since most LCR meters have a resistor, usually 100  $\Omega$ , in series between the oscillator and the unknown to be measured, the number of

turns should be chosen such that the reactance of the core is at least 10  $\Omega$ . This condition ensures that a minimum of 10% of the test signal is applied to the core.

With the frequency set and voltage adjusted for test conditions, the LCR meter will measure  $R_s$  and  $L_s$ . Caution: When measuring very small value reactances, be sure to test the accuracy of the measurement instrument.

## Changes in Inductance versus Temperature & Curie Temperature

These two tests may be performed using an inductance meter and a temperature controlled oven. The inductance meter will measure  $R_s$  and  $L_s$  as described above.

*Equipment:* Precision LCR meter  
Temperature Controlled Chamber  
for DUT

*Test Conditions:* Flux Density <10 Gauss  
Temperature as specified

*Frequency:* 10 to 100 kHz.

The cores to be tested are placed in the temperature chamber and subjected to two stabilizing temperature cycles, with approximately two hours at each temperature.

The first inductance measurement,  $L_1$  is made at the lowest temperature,  $\theta_1$ , after a thirty minute soak at that temperature. This procedure is repeated up to the highest specified temperature,  $\theta_2$ . A measurement made in the 20°C to 25°C range is considered the reference inductance,  $L_{ref}$ , at the reference temperature,  $\theta_{ref}$ .

After measuring the highest temperature, a final measurement should be made again at the reference temperature. Both measurements of the reference inductance should be the same within the bridge accuracy. If these two readings are significantly dissimilar, more temperature stabilizing cycles may be needed to eliminate irreversible inductance changes in the samples.

# Ferrite Property Measurement

From the inductance reading at various temperatures, the temperature coefficient of inductance may be calculated from

$$T.C. = \frac{L_{\theta_2} - L_{ref}}{L_{ref} (\theta_2 - \theta_{ref})} = \frac{L_{\theta_2} - L_{\theta_1}}{L_{ref} (\theta_2 - \theta_1)}$$

where all terms are as defined above.

For Curie Temperature measurement, temperature is slowly increased while inductance is monitored. The temperature at which core inductance decreases to 10% of the room temperature value is the Curie Temperature.

## Flux Density, Residual Flux Density, Coercive Force, & Amplitude Permeability

There are four intrinsic material parameters that can be determined from the B-H loop measurement. The core under test is used as a transformer and the relationship between winding current (H) and secondary winding integrated voltage (B) is measured. This relationship is displayed using the "X versus Y" display mode on an oscilloscope. Magnetic terms are readily expressed in electrical terms to calibrate the display in units of Oersteds (Oe) versus Gauss (G). Once this calibration is achieved, salient points on the B-H curve may be easily obtained.

**Equipment:** Function Generator  
Amplifier  
RC Network  
Dual Channel Oscilloscope

The test circuit is as shown at the right. Resistor  $R_1$  is kept small in comparison with the inductive reactance of the wound sample. Cores must be properly installed and wound with primary and secondary winding. Field strength, H, is set by varying the current which is read as voltage across resistor  $R_1$ .

$$H_{[Oe]} = \frac{0.4\pi nI}{l_{e[cm]}} = \frac{0.4\pi n_p V_p}{l_{e(cm)} R_1}$$

Flux density in the core is determined by integrating the secondary voltage using the RC circuit.

$$B_{[G]} = \frac{R_2 C V_p 10^8}{n_s A_{e[cm^2]}}$$

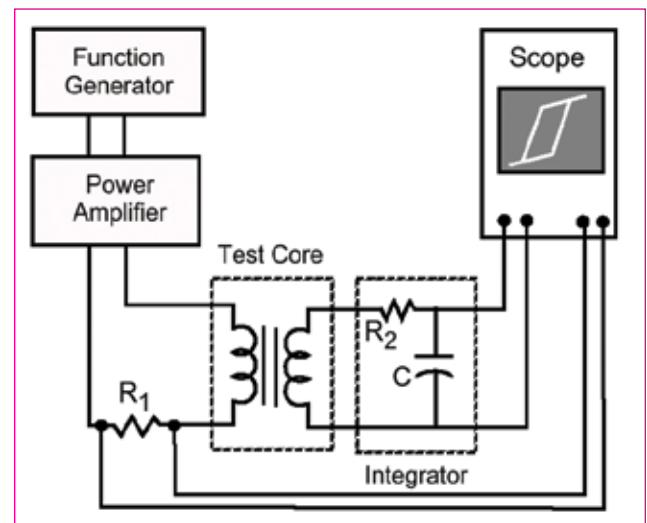
where  $R_2$  is the integrating resistance, and C is the integrating capacitor.

From the displayed hysteresis loop saturation flux density,  $B_s$ , valueVs for coercive force,  $H_c$ , and residual flux density,  $B_r$ , may be determined once the oscilloscope is calibrated for field strength H and Flux Density.

Finally, amplitude permeability,  $\mu_a$ , is given by

$$\mu_a = \frac{B}{H}$$

where B represents peak flux density between 10 Gauss and saturation, an H is the corresponding field strength.



Test set up for measuring parameters of the B-H Loop.

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# Ferrite Property Measurement

## Pulse Characteristics

An open collector drive circuit is used to drive a pulse through a transformer with the secondary open circuited. The effect of the transformer on the pulse is observed by monitoring waveforms.

**Equipment:** Pulse Generator  
DC Power Supply  
Pulse Drive Circuit—appropriate for application  
Dual Channel Oscilloscope  
Current Probe

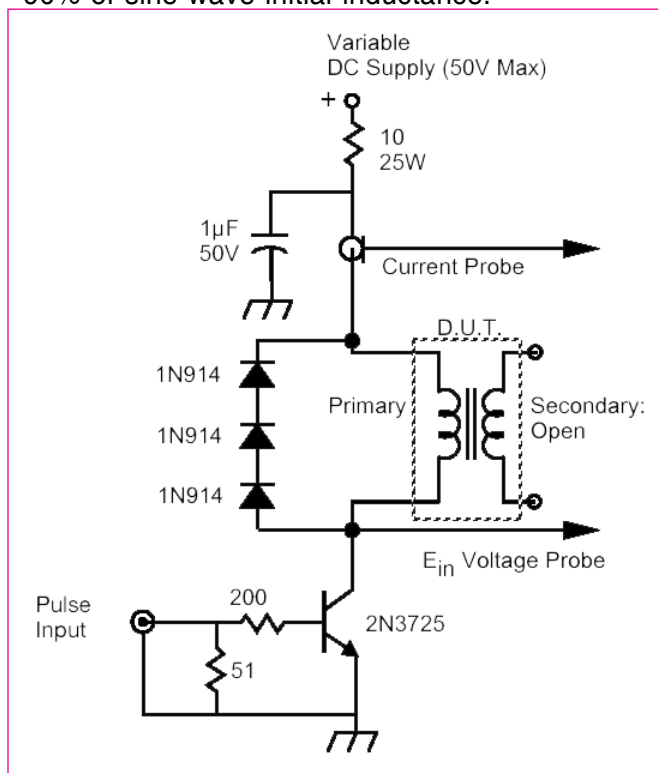
**Test Conditions:** Pulse Amplitude, Pulse Width, and Pulse Repetition Rate as specified.

Temperature; 23°C ± 3°C.

The test toroid to be measured is wound with a sufficient number of turns to produce at least 100 µH of inductance. The core is excited by applying square voltage pulses. The test circuit is shown below.

Pulse inductance,  $L_p$ , pulse Inductance Factor,  $A_{LP}$ , and the voltage time product, E-T, are measured in accordance with section 16.7 of IEC367-1.

Pulse inductance is specified as greater than 90% of sine wave initial inductance.



Test set up for measuring pulse characteristics

## Power Loss

Power loss is readily measured using a Volt-Amp-Watt (VAW) meter.

**Equipment:** Signal Generator  
Power Amplifier  
Clark Hess 256 VAW Meter  
Temperature Chamber

The equipment is connected as shown below.

Frequency is set and voltage is adjusted to the desired flux density level, given by the relation

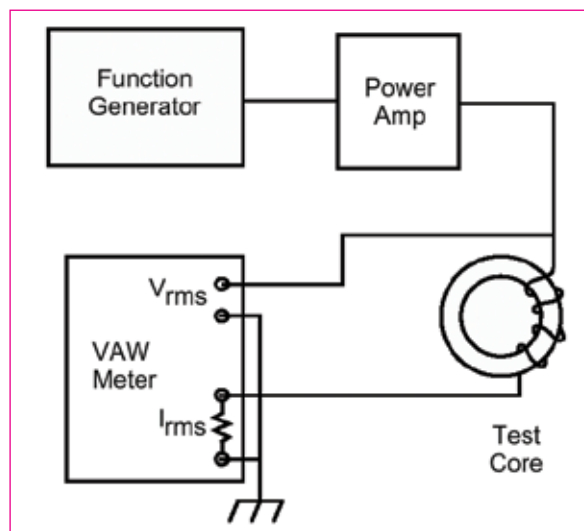
$$E_{[Vrms]} = 4.44fnB_{[G]}A_{[cm]}^2 10^{-8}$$

Power losses are indicated by the VAW meter in watts. Measurements are made as rapidly as possible to avoid temperature rise in the samples.

Material power loss density is determined by dividing the measured power loss by the effective volume of the ferrite core.

A VAW meter may also be used to measure magnetizing current,  $I_m$ . This value can be used to calculate the winding loss ( $I_m^2 R_{ac}$ ), a part of the total measured power loss.

Accuracy at higher frequencies is highly dependant on phase shift between the voltage and current.



Test set up for measuring power loss.

# Ferrite Property Measurement

## Measurement of Impedance Of Ferrite Components

The most common property referenced for soft magnetic materials is permeability. Impedance is a complex property comprised of imaginary (reactive) and real (resistive) components. At the lower end of the RF scale, impedance can be calculated from inductance as  $Z \approx 2\pi fL = X_L$  and is dominated by the reactive component of permeability.

As frequency increases, impedance is driven by the resistive component and can be calculated as  $Z = \sqrt{R^2 + (j\omega L)^2}$ , where R represents the resistive component and  $j\omega L$  represents the reactive component. At higher frequencies permeability will approach zero and impedance will reach a maximum value comprised of a purely resistive component. Impedance, like permeability, varies with temperature, frequency, signal current, DC bias, and the presence of any extraneous fields.

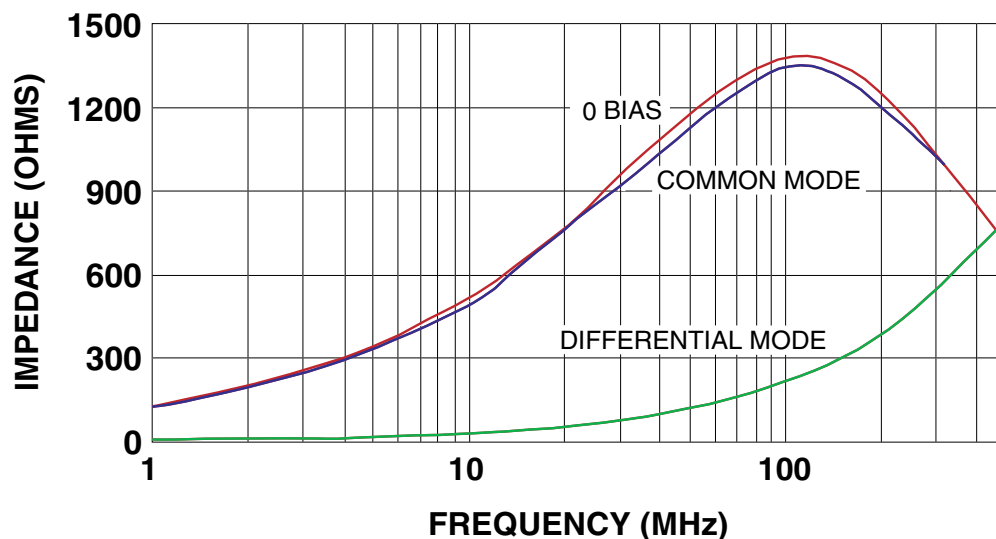
The useful impedance obtained from a ferrite component depends on its application, number of turns, and winding method. See below for

an illustration of the effect of differential versus common mode winding techniques on the net impedance of a core.

Impedance measurements are made on an RF impedance analyzer. Measurements for this catalog were made on a Hewlett-Packard E4991A Network/Spectrum Analyzer with a E4991A Impedance Test Kit. All impedance curves represent gross measurements with number of turns and DC Bias current applied as shown (unless noted other-wise). In all cases the length of the conductive path between the part under test and the test fixture is kept to a minimum and in a fixed position to minimize parasitic capacitance.

All impedance measurements with DC Bias utilize the internal circuitry of the impedance analyzer. Measurements are also possible with an external source of DC current using an RF choke and a blocking capacitor to isolate the bias circuit from the RF circuit.

## IMPEDANCE vs. DC BIAS COMMON vs. DIFFERENTIAL MODE WINDING



28T0155-200, 10 AMP-TURNS

These curves show the effect of ten amp-turns of DC bias on the same core wound two different ways. In the differential mode, wherein there is a single winding carrying direct current, the core is pushed far into saturation (ten amp-turns on a T0155-200 corresponds to 13.7 Oersteds). In the common mode, wherein the direct current returns through a coil of the opposite winding direction and an equal number of turns, the only deviation from zero-bias arises from leakage inductance, which is inherently low in toroids.

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# Terminology

The following glossary of terms is adapted from the Magnetic Materials Producers Association publication SFG-92 and other sources.

**Air Core Inductance ( $L_0$  [Henry]):** The inductance that would be measured if the core had unity permeability and the flux distribution remained unaltered.

**Circular Mils (c.m. [mils<sup>2</sup>]):** The cross sectional area of a circular conductor calculated as a square conductor, ie, area in c.m. is  $D^2$ , where D is the diameter of the wire. See also "Square Mils."

**Coercive Force ( $H_c$  [Oe; Amp/m]):** The magnetization field strength required to bring the magnetic flux density of a magnetized material to zero. See "Field Strength."

**Common Mode Current:** The component of signal current that induces electric and magnetic fields that do not tend to cancel one another. For example, in a circuit with one outgoing signal conductor and one return ("ground") conductor, the common mode current is the component of the total signal current that flows in the same direction on both conductors. Common mode current is the primary source of EMI in many electronic systems.

**Common Mode Type I:** On a single phase Wye bus, the conduction mode in which phase, neutral, and ground currents are in phase. The return current path is through the ground plane and the case.

**Common Mode Type II:** On a single phase Wye bus, the conduction mode in which phase and neutral currents are in phase, but the green wire currents are the return path, therefore 180° out of phase.

**Common Mode Voltage:** The voltage that drives directed common mode (noise) currents.

**Core Constant ( $C_1$  [cm<sup>-1</sup>; mm<sup>-1</sup>]):** The summation of the magnetic path length of each section of the circuit divided by the corresponding area of the same section. See section entitled "Magnetic Design Formulas."  $C_1$  is a frequently useful ratio in the analysis and prediction of core performance.

**Core Constant ( $C_2$  [cm<sup>-3</sup>; mm<sup>-3</sup>]):** The summation of the magnetic path length of each section of the magnetic circuit divided by the square of the corresponding magnetic area of the same section. See section entitled "Magnetic Design Formulas."

**Curie Temperature ( $T_c$  [°C]):** The transition temperature above which a ferrite loses its ferromagnetic properties. Usually defined as the temperature at which  $\mu_i$  falls to 10% of its room temperature value.

**Dielectric Withstanding Voltage (DWV [V]):** DWV is the voltage level at which the dielectric breaks down, allowing conduction between isolated conductors or between a conductor and the core. Isolation, or Hipot is the ability of a transformer to withstand a specific breakdown voltage between the primary and secondary windings.

**Differential Mode:** A current conduction mode in which currents, relative to two conductors, are flowing 180° out of phase, with equal magnitude within the conductors.

**Differential Mode Current:** The intended signal currents that are equal and oppositely directed on pairs of signal and return ("ground") conductors.

**Differential Mode Voltage:** The voltage that drives equal and oppositely directed currents to achieve an intended circuit function; the source of differential mode currents.

**Disaccommodation (D):** The proportional change of permeability after a disturbance of a magnetic material, measured at constant temperature, over a given time interval.

# Terminology

**Disaccommodation Factor (DF):** The disaccommodation factor is the disaccommodation after magnetic conditioning divided by the permeability of the first measurement times  $\log_{10}$  of the ratio of time interval.

**Effective Area ( $A_e$  [cm<sup>2</sup>; mm<sup>2</sup>]):** For a magnetic core of a given geometry, the magnetic cross-sectional area that a hypothetical toroidal core of the same material properties would possess to be the magnetic equivalent to the given core.

**Effective Length ( $l_e$  [cm; mm]):** For a magnetic core of a given geometry, the magnetic length that a hypothetical toroidal core of the same material properties would possess to be the magnetic equivalent to the given core.

**Effective Volume ( $V_e$  [cm<sup>3</sup>; mm<sup>3</sup>]):** For a magnetic core of a given geometry, the magnetic volume that a hypothetical toroidal core of the same material properties would possess to be the magnetic equivalent to the given core.

**Field Strength (H [Oe; Amp/m]):** The parameter characterizing the amplitude of ac or dc field strength. Field strength is determined by the magnitude of current and geometry of the windings.

**Flux Density (B [Gauss; Tesla]):** The corresponding parameter for the induced magnetic field in an area perpendicular to the flux path. Flux density is determined by the field strength and permeability of the medium in which it is measured.

**Impedance Z [Ohm]:** The impedance of a ferrite may be expressed in terms of its complex permeability:

$$Z = j\omega L_s + R_s = j\omega L_o (\mu'_s - j\mu''_s) \text{ (ohm)}$$

**Incremental Permeability ( $\mu_\Delta$ ):** The permeability of a magnetic material about a specified operating point and applied H (especially under DC bias). The incremental permeability is expressed as the slope of the B-H characteristic about the given operating point.

$$\mu_\Delta = \frac{\Delta B}{\Delta H}$$

**Inductance Factor ( $A_L$ ):** A constant for a given geometrical shape that when multiplied by the square of the number of turns, gives the inductance in nano Henrys. Initial permeability (flux density of less than 10 Gauss) is assumed in the inductance factor.

**Insulation Resistance [Ohm]:** The insulation properties of the insulating material as measured in Ohms.

**Leakage Flux:** Leakage flux is the small fraction of the total magnetic flux in a transformer or common mode choke that does not contribute to the magnetic coupling of the windings of the device. In a transformer with a single set of primary and secondary windings, the leakage flux is that portion of flux that is produced by the primary that does not link the secondary. The presence of leakage flux in a transformer or common mode choke is modeled as a small "leakage" inductance in series with each winding. In a multi-winding choke or transformer, leakage inductance is the inductance measured at one winding with all other windings short circuited.

**Leakage Inductance ( $L_\lambda$  [Henry]):** That component of inductance that results from non-ideal coupling of flux to a core and/or other windings. As applied to the primary side of a transformer, the quotient of flux *not* coupled to the secondary winding and the current in the primary winding. As applied to an inductor, the quotient of flux outside the core and the current through the winding. In a multi-winding choke or transformer, leakage inductance is the inductance measured at one winding with all other windings short circuited.

**Loss Factor ( $\tan\delta/\mu_i$ ):** The phase displacement between the fundamental components of the flux density and the field strength divided by the initial permeability. This term is essentially normalized loss. Note that  $1/\tan\delta$  equals Q. This term is most useful as an indicator of the useful high Q bandwidth of a material. Above a specific frequency, depending on the material, loss factor normally undergoes a rapid increase due magnetic resonance. Note that a high Q is not desirable in all applications, especially EMI or filtering.

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# Terminology

**Loss Tangent:** The measure of the loss of a magnetic material at high operating frequencies due to the oscillation of microscopic magnetic regions within the material. The loss tangent is expressed as the ratio of the imaginary permeability component  $\mu''$  to the real permeability  $\mu'$  of the material.

**Magnetic Constant ( $\mu_0$  [Henry/m]):** The permeability of free space. The constant  $\mu_0$  has a value of  $4\pi \times 10^{-7}$ .

**Magnetic Field Intensity or Magnetizing Force ( $H$ ):** The mmf per unit length.  $H$  can be considered to be a measure of the strength or effort that the magnetomotive force applies to a magnetic circuit to establish a magnetic field.  $H$  may be expressed as  $H = NI/\mathcal{L}$ , where  $\mathcal{L}$  = the mean length of the magnetic circuit in meters.

**Magnetic Hysteresis:** In a magnetic material, the irreversible variation of the flux density or magnetization which is associated with the change of magnetic field strength and is independent of the rate of change. Hysteresis results in the square or "open" characteristic of the B-H loop. Because it is irreversible, hysteresis results in lost energy. The amount of energy lost is related to the area within the B-H loop traversed.

**Magnetically Soft Material:** A magnetic material with a low coercivity.

**Magnetomotive Force (MMF [Amp]):** The magnetic field which induces a magnetic flux in a magnetic circuit. The total magnetomotive force is the product of turns and current. Also, the product of Magnetic Field and coil length.

**Mean Length Turn (MLT [cm; mm]):** The average length of a single turn around the toroid. Values in this catalog are given for single layer coils. In multi-layer coils, the length of each successive layer is longer resulting in a longer average turn length.

**Parasitic Capacitance ( $C_p$  [F]):** Unintentional capacitance resulting from close physical proximity of two conductors. The copper comprising the wire is separated by its insulation from the core. The capacitance is proportional to area (wire diameter) and inversely proportional to separation.

**Permeability ( $\mu$ ):** The extent to or ease with which a material can be magnetized, often expressed as the parameter relating the magnetic flux density  $B$  induced by an applied magnetic field intensity  $H$ , as  $B = \mu H$ . The "absolute" permeability of a given material is expressed as the product of its relative permeability  $\mu_r$  (a dimensionless constant) and the free space constant  $\mu_0$ .

**Permeability, amplitude ( $\mu_a$ ):** The quotient of the peak value of flux density and peak value of applied field strength at a stated amplitude of either, with no static field present.

**Permeability, incremental ( $\mu_{\Delta}$ ):** This is the permeability derived from the incremental difference of  $B$  and  $H$  ( $\Delta B/\Delta H$ ), as given by a small ac signal with a static field, or bias, present. Also, minor loop permeability.

**Permeability, effective ( $\mu_e$ ):** For a magnetic circuit constructed with an air gap(s), the permeability of a hypothetical homogeneous material which would provide the same reluctance.

**Permeability, Free Space ( $\mu_0$ ):** The permeability of free space, a constant.

**Permeability, initial ( $\mu_i$ ):** This is the permeability of an initially de-gaussed core driven with a small signal ( $2 < B < 10$  Gauss typical) such that the permeability of a minor loop centered on the origin is measured. The drive level is specified as  $< 10$  Gauss, and is such that the minor loop is "inside" the major loop. Note that the (amplitude) permeability initially increases with increasing field strength.

**Permeability, Pulse ( $\mu_P$ ):** Under stated conditions, permeability obtained from the ratio of the rate of change in flux density to the rate of change in applied field strength of the pulse field.

**Power Loss Density ( $P$  [mW/cm<sup>3</sup>; kW/m<sup>3</sup>):** The power absorbed by a body of ferromagnetic material and dissipated as heat when the body is subjected to an alternating field, which results in a measurable temperature rise. The total loss is divided by the volume of the body.

**Quality Factor (Q):** The ratio of energy stored to energy lost (reactance to resistance). For a series LR circuit,  $Q$  is  $\omega L/R$ . For a parallel LR circuit,  $Q$  is  $R/\omega L$ .



# Terminology

**Remanence (Br [Gauss; Tesla]):** The flux density remaining in a magnetic material when the applied field strength is reduced to zero.

**Resistance:** A measure of the degree to which an object opposes the passage of an electrical current resistance defined as :

$$R = \frac{V}{I}$$

where V = voltage, I = current. At Oe bins levels resistance is also

$$R = \frac{\vartheta \rho}{A}$$

where  $\vartheta$  = length of conductor,  $\rho$  = resistivity, A = cross section area.

**Resistivity ( $\rho$ ):** The intrinsic property measured in ohm-cm that quantifies a material's opposition to free electron motion. Resistivity is the reciprocal property to conductivity. The resistance of a homogeneous material of uniform cross section A and length I can be found by:

$$R = \frac{\vartheta \rho}{A}$$

**Rise Time ( $\tau_r$  [sec]):** Rise time of a square pulse is defined as the shortest time required for the voltage level to change from a "low" state to a high "state." Time is customarily measured between voltage levels 10% and 90% of the "high" amplitude.

**Saturation:** The point at which the flux density B in a magnetic material does not increase with further applications of greater magnetization force H. At saturation, the slope of a materials's B-H characteristic curve becomes extremely small, with the instantaneous permeability approaching that of free space (relative permeability = 1.0)

**Saturation Flux Density ( $B_s$  [Gauss; Tesla]):** The maximum intrinsic induction possible in a material. This is the flux level at which additional H-field produces no additional B-field.

**Single-Layer Winding:** A winding for toroidal cores which will result in the full utilization of the inside circumference of the core without overlapping turns. Both the wire gauge and the thickness of the insulation will effect the number of turns which will fit on a single-layer winding.

**Square Mils (mils<sup>2</sup>):** The cross sectional area of a circular conductor calculated as a circle, ie, area is  $\pi r^2$ , where r is in mils. See also "Circular Mils."

**Temperature Coefficient (T.C.):** The normalized change of the quantity considered (inductance, for instance), divided by the difference in temperature producing it.

**Turns Ratio:** The ratio of the number of turns on the primary to the number of turns on the secondary.

**Volt Second Product (ET [ $V_s$ ]):** The ET product is a parameter used to measure the transformer's ability to maintain and support a pulse signal without saturating the core. It is determined as the product of the voltage applied at the primary and the time required for the magnetizing current to reach 1.5 times its linear value. Values for ET are dependent on the core geometry, core material, and the number of turns on the winding.

**Volume Resistivity ( $\rho$  [Ohm-cm]):** The resistance measured by means of direct voltage of a body of ferromagnetic material having a constant cross-sectional area.

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